FISHERIES DIVISION
RESEARCH REPORT

Number 2009 December 21, 1994

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DNR
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TOTAL NUMBER OF COPIES PRINTED: 300 TOTAL COST: $299.00 COST PER COPY: $ 1.00
Michigan Department of Natural Resources

Cover: Recovering fish at the downstream blocking net following application of rotenone in the Galien River.

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Efficiency of Sampling River Fishes with Rotenone

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Abstract—During 1987-92 we examined efficiency of rotenone sampling at 42 sites on 13 river systems in Michigan's lower peninsula. At each site, fish were collected by electrofishing, marked with a fin clip, and released into the treatment site shortly before the application of rotenone. Marked fish were then enumerated from the rotenone sample and recapture efficiency determined. Overall recapture efficiency was 0.43 and variability was large (±2 SD = 0.87). We grouped data by taxa, inch, discharge, and light transmittance; and developed models that predict recapture efficiency. At sites with low discharge and high transmittance, recapture efficiencies averaged from about 0.59 (sunfishes, suckers, and others) to 0.66 (minnows) for fish up to 9 in. For larger fish, efficiencies increased to about 0.89. At sites with high discharge or low transmittance, efficiencies for small fish (1 in) were only about 0.19-0.24 but increased asymptotically to about 0.84 for fish larger than 14 in. At all sites, efficiency was low (about 0.18) for benthic fishes (mudminnows, darters, and sculpins). Samples of fishes collected with rotenone provide fair estimates of total standing crop of a stream reach (about 75% of actual) but are not useful for describing numerical abundance (only about 33% of actual) unless corrected for biases. We recommend that additional data on recapture efficiencies be collected to improve precision and accuracy of efficiency models.

Rotenone, a fish toxicant, is used to sample fishes in rivers and streams, particularly when information on the entire fish community is desired (Davies and Shelton 1983; Hottell et al. 1983; Seelbach et al. 1988). Rotenone is more efficient and less biased with regard to fish taxon, fish size, and habitat type than alternative sampling methods. These variables cause significant biases to study community structure when electrofishing is used in small streams (Larimore 1961; Boccardy and Cooper 1963; Reynolds 1983), and these biases are magnified in larger rivers as overall efficiency decreases (Penczak and Zalewski 1973; Jacobs and Swink 1982; Towns 1984; Bayley and Dowling 1993). Compared to rotenone samples collected in large rivers, electrofishing produced only 1-29% of the number of individual fishes and 24-74% of the number of fish species (Nelson and Smith 1980; Jacobs and Swink 1982; Towns 1984). Netting techniques used in river sampling are also known to be very selective for particular fish taxa and size groups (Hubert 1983).

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[1] Retired

Sampling with rotenone, however, is neither 100% effective nor unbiased. Recovery of marked fish in ponds and small lakes has been estimated at about 50-90% (Ball 1948; Krumholz 1950; Shireman et al. 1981; Bayley and Austen 1988, 1990). Similar recovery efficiencies of 25-90% have been found in streams and rivers (Boccardy and Cooper 1963; Johnson and Pasch 1976; Coomer and Holder 1980; Jacobs and Swink 1982; Hottell et al. 1983; Bayley and Dowling 1990; V. Paragamian, Idaho Department of Fish and Game, personal communication). In addition, sampling with rotenone can fail to collect some rare species (Jacobs and Swink 1982; Towns 1984). Recoveries following rotenone application can be biased by factors affecting either efficiency of the fish kill or efficiency of subsequent collection efforts. Biases related to fish taxa, fish length, water temperature, size of sampling area, and physical character of sampling area have been demonstrated (Coomer and Holder 1980; Jacobs and Swink 1982; Hottell et al. 1983; Bayley and Austen 1990; Bayley and Dowling 1990).

Since a successful trial on the Grand River in 1978 (Nelson and Smith 1980), sampling with rotenone has become a standard methodology for surveying fish communities in Michigan rivers (Seelbach et al. 1988). An understanding of the biases of this procedure is needed so that survey results can be converted to estimates of community parameters like species composition and standing crop. Our objectives were to: (1) determine the mean efficiency of rotenone sampling in Michigan streams and rivers; (2) examine variation in efficiency due to fish taxa, fish size, and characteristics of the sampling site; and (3) develop predictive models of recovery efficiency that account for existing biases.

Study sites

During 1987-92 we examined efficiency of rotenone sampling at 42 sites on 13 river systems in Michigan's lower peninsula. Streams sampled were all considered warmwater or coolwater systems, draining watersheds with surficial geology varying in amounts of glacial outwash sands, mixed morainal deposits, sorted fine tills, and lake plain sediments. Sites varied in size from mid-sized streams to small rivers; August discharge (base flow) at these sites ranged from 10 to 300 ft^3/s and mean channel widths at base flow varied from 19 to 115 ft. Histograms of discharge, mean channel velocity, mean channel width, mean channel depth, and adjusted transmittance for the sampled sites are shown in Figure 1 (data are presented in Appendix 1). We measured percent transmittance of light through 1 cm water samples from each site using a spectrophotometer (calibrated at 750 nm). We calculated adjusted transmittance as:

$$X^Y,$$

where,

X=percent transmittance
Y=mean channel depth (cm).

Adjusted transmittance will be referred to as "transmittance" in this report.

Methods

At each site, we collected as many fish as possible during about 1 h using DC electrofishing equipment. We used a 3-phase AC generator with output rectified to DC that produced about 300 V and 3.5 A. Sampling was done while wading and towing the generator in a small boat. Fish were collected within the site to be treated with rotenone. We typically collected about 100-200 fish per site but composition, in terms of species and inch groups, was highly variable. Fishes common to wadable shoreline habitats and vulnerable to electrofishing were most abundant in our samples. In all we marked 5,236 fish: 1,602 minnows, 114 carp, 703 suckers, 70 catfish, 127 pike, 158 mudminnows, 37 pirate perch, 71 sculpins, 2,020 sunfish, and 334 darters. Each fish was measured to the nearest inch group and given an upper caudal fin clip. Fish were allowed to recover in perforated containers placed in the stream, and were released into the treatment site following the deployment of downstream blocknets and shortly

(<30 min) before the upstream application of rotenone.

Standard procedures for rotenone surveys were employed (Seelbach et al. 1988). Block nets were placed at the midpoint and lower end of each site. Where streams were small and clear, only the lower block net was used. Where water velocities were swifter, larger-mesh block nets were used, and several small-mesh fyke nets were placed just downstream of the lower block net to subsample small fish escaping through the block net. Rotenone was applied (3 ppm) at the upstream end of the station for 45 min and, as rotenone (marked by dye) reached the lower end, potassium permanganate was applied (4 ppm) as a neutralizing agent for 55 min. Efforts were made to collect all fish. Distressed fish that swam to the surface were netted with hand nets when possible. The entire site was searched for fish that could be picked off the bottom with hand nets. When all downstream movements of fish ceased (about 2 h), fish were collected from the block nets and fyke nets. Each fish collected during the survey was identified to species and examined for an upper caudal fin clip. All clipped fish were measured to the nearest inch group.

To minimize variance, raw mark and recapture data were grouped by site, inch group, and family (common carp *Cyprinus carpio* was treated as a separate taxon due to its unusual size and resistance to rotenone). Bayley and Dowling (1990) similarly recommended grouping data by taxa. Mean recapture efficiency and its variance were calculated. We examined sources of this variation as follows:

We developed taxon groupings based on similarities among taxa. Mean recapture efficiencies were calculated by family, inch group, discharge (separated into 2 groupings according to a frequency histogram), and transmittance (similarly separated into 3 groupings). We compared mean recapture efficiencies (±2 SE) among families for similar inch, discharge, and transmittance groups; and ultimately grouped families with similar efficiencies into 3 taxon groups with distinct efficiency responses. These groups--topwater (minnows), midwater (sunfishes, suckers, catfishes, carp, perches, and pikes), and benthic (darters, sculpins, mudminnow, pirate perch)--reflected well the general behavioral responses to rotenone that we observed during surveys. For example, stressed minnows (that consistently had high recapture rates) tended to swim actively at the surface of the river, which brought them more readily to the downstream collection net or netters. Stressed benthic fishes (that consistently had low recapture rates) typically remained near the stream bottom and often become lodged among rocks or woody debris, making them difficult to collect.

The initial data set was composed of 1,466 records (i=1,466); each containing site location, taxon group, inch group, number of fish marked (n_i), number of fish recaptured, transmittance, discharge, and mean stream velocity. Any records with n_i <3 were discarded. At each site location taxon groups were combined by inch group to form 413 records (j=1-413), to form the final 3 taxon groups (topwater, midwater, and benthic). Recaptured efficiencies were then calculated for each recprd (j) as number recaptured (r_j) divided by number marked (n_j). We weighted each measure of efficiency by the corresponding n_j as follows. Each record was expanded to form n_j records, each with the number of fish marked equal to one, and each having the efficiency of the original record (j). For example, if a record contained 45 fish marked (n_j), 9 fish recaptured (r_j), and an efficiency of 0.20 (r_j /n_j); we created 45 records that each contained 1 fish marked, 0.20 fish recaptured, and an efficiency of 0.20. The resulting data set contained 4,788 records.

Using the resulting dataset, we developed models relating recapture efficiency to inch group and site conditions. We applied multiple linear regression to each taxon group, with recapture efficiency as the dependent variable and inch group, velocity, transmittance, and discharge as independent variables. Regression analyses were done using the software package SPSS for Windows (Version 6.0, SPSS Inc., 1993) at α=0.05. Outliers were identified (as outside ±2 SD of the regression equation) and removed from the dataset. This represented about 5% of the records. In these analyses, inch group was consistently a significant variable, transmittance and discharge were significant in some cases, but velocity was never a significant variable.

Scatter plots of taxon groups where discharge was significant suggested that distinct distributions of recapture efficiency existed for conditions of low discharge (0-99.99 ft^3/s) compared to conditions of high discharge (≥100 ft^3/s). For example, mean efficiency for midwater fishes was 0.44 at discharges <100 ft^3/s and 0.33 for discharges ≥100 ft^3/s (Figure 2). We therefore categorized observations as either low or high discharge. Observations were similarly identified as other low transmittance (0-0.19) or high transmittance (≥0.2). Mean efficiency for midwater fishes was 0.38 for transmittance <0.20 and 0.57 for transmittance ≥0.20 (Figure 3). We then developed a new dataset comprised of the mean recapture efficiency for each inch, taxon, discharge, and transmittance group; eliminated any group with fewer than 10 records; and combined inch groups for the larger, less-abundant taxa.

Variances of recapture efficiencies were not homogeneous between groups (Levene's test), so we could not use multiple linear regression for this dataset. Instead, for each combination of discharge and transmittance groups, we derived three representative data points for each inch group (mean, +2 SE, and -2 SE), and built predictive models of recapture efficiency with inch group as the independent variable. This method gave each inch group equal weight, provided better fit of our models to inch-group means, and accounted for variability within our data. Where this relationship appeared curvilinear and asymptotic, polynomial regression was used. Where relationships were similar between discharge groups or transmittance groups, data were combined and a single model generated. Equations for estimating total fish abundance (±2 SE) from a rotenone sample are included with Figures 4-8. Equations for each taxon group are presented by discharge, transmittance, and inch groups (where appropriate).

Total abundance was calculated as:

$$\left(\frac{sa}{ere}\right),$$

where,
sa = sample abundance
ere = estimated recapture efficiency.

Variance of total abundance was calculated as:

$$\left(\frac{sa}{ere}\right)^2 * \left(\frac{vere}{ere^2}\right),$$

where,
vere = variance of estimated recapture efficiency,

(Freese 1962). We demonstrated the use of these equations for estimating total abundance by taxa from sample data at one site, the St. Joseph River at Athens Road (characterized by low transmittance and high discharge). We also calculated total standing crop by taxa for both sample and estimated data using length-weight regressions (Schneider et al. 1991).

Results

Overall recapture efficiency was 0.43 and variability was large (±2 SD = 0.87). However, grouping data by taxon, inch, discharge, and transmittance allowed us to develop statistically significant (3 of 5) models that predicted recapture efficiency with acceptable levels of variability (±2 SE ≈ 0.15).

Two distinct models were developed for predicting recapture efficiency of topwater fishes, one for low discharge and one for high discharge. Recaptures were not influenced by transmittance. At low discharge, efficiencies remained constant (mean = 0.63) as length increased (Figure 4). At high discharge, efficiencies for small (1-2 in) fish were only 0.24-0.38, but these increased asymptotically to 0.67-0.71 for larger fish (5-6 in; Figure 5).

Two predictive models were developed for midwater fishes, one for conditions of low discharge and high transmittance (Figure 6), and one for all other conditions (Figure 7). For fishes up to about 9 in long, the models were very similar in form to those for topwater fishes but efficiencies were lower. Under conditions of low discharge and high transmittance, efficiency of midwater fishes was constant for 1-9 in fish at 0.59. Efficiency increased sharply to 0.89 as length increased to 12 in. Lacking data for larger fish, we used the mean efficiency for 10-16 in fish of 0.89. If, instead, efficiency continued to increase, it would have reached 1.00 at about 16-20 in. For all other conditions, efficiencies of midwater fishes rose asymptotically from 0.19 (for 1-in fish) to 0.84 (for 24-in fish).

Only one model was developed for benthic fishes, as discharge, transmittance and length were not significant factors affecting recaptures. Mean recapture efficiency was 0.18 (Figure 8).

Application of equations developed to expand a sample dataset (Figures 4-8) showed that sampling with rotenone only collected about 33% of the estimated actual number of fish present (Figure 9). About 33% of most families were collected but only 18% of darters were collected. The standing crop of fish based on the sample collection was about 75% of the estimated actual standing crop (Figure 10). About 77% of carp and suckers were collected and these larger fishes comprised the bulk of the total standing crop. Only about 17-38% of smaller-sized sunfish, minnows, and darters were collected; but this did not greatly impact overall standing crop.

Discussion

Our recapture efficiencies, in the range of about 20-80% in streams and small rivers with discharges up to 300 ft^3/s, were very similar to those reported in other studies. Bayley and Dowling (1990) reported efficiencies of 25-65% for Illinois streams (discharges up to 194 ft^3/s). Boccardy and Cooper (1963) found that, even when sampling brook trout (a species sensitive to rotenone) in small brooks, efficiencies were only 63-90%. Efficiencies in fairly large rivers (1,000-3,000 ft^3/s), measured primarily for larger-sized fishes, have been about 40-80% (Johnson and Pasch 1976; Coomer and Holder 1980; Jacobs and Swink 1982; Hottell et al. 1983).

Previous studies in both streams and ponds have identified that fish taxon, fish length, size of sampling area, water temperature, and physical character of sampling area are all important factors that affect variability in recapture efficiency (Bayley and Austen 1990; Bayley and Dowling 1990). We likewise found fish taxon, fish length, stream discharge (indicative of stream size), and transmittance (indicative of water clarity) to be significant factors. Each of these factors affects either efficiency of the fish kill or efficiency of subsequent collection efforts.

Efficiency of kill was primarily related to fish taxon, as susceptibility to rotenone varies among taxa. For example common carp and bullheads are known to be extremely tolerant of rotenone (Krumholz 1950; Rach and Gingerich 1986). Efficiency of kill might also be affected by variations in application procedures, water temperatures, or complexity of stream channel. Peterson and Bayley (1993) demonstrated that a few fish survive applications of rotenone in fairly small streams <194 ft^3/s.

Efficiency of collection can be affected by the degree to which fish can be immediately captured while struggling at the surface, the degree to which fish swim (or are swept) downstream to the block net, predation upon struggling fish, visibility of fish that either sink to (or become lodged near) the bottom, or the size of the area sampled. Availability for collection at the surface is primarily a function of fish taxa. Some species react to rotenone by swimming actively at the surface or at mid-water, while others dart about erratically at or near the stream bottom. The degree to which fish reach the block net(s) is a function of taxa-specific swimming behaviors and water velocity. We found that fishes that reacted to rotenone with active, topwater swimming that brought them to the block net (minnows) had the highest recapture efficiencies. Decreased water clarity did not reduce efficiencies for topwater fishes. Bayley and Dowling (1990) similarly found that minnows had the highest mean recapture efficiencies in Illinois streams. Bayley and Dowling (1990) also found that water velocity had a significant positive impact on efficiency, however, it was not significant in our analysis. Dying fish are preyed upon by fishes, other predators, and scavengers (Krumholz 1950); and predation is likely highest on smaller fishes. Collection of fishes that sink to, or become lodged near, the stream bottom is primarily a function of their visibility. Increased fish size, increased water clarity, decreased depth, and decreased presence of cover (rocks, woody debris, or vegetation) all improve visibility and resulting collection of fish (Shireman et al. 1981; Bayley and Austen 1988, 1990; Bayley and Dowling 1990). Small, benthic fishes had the lowest efficiencies both in our study and in Illinois streams (Bayley and Dowling 1990). Collections are more efficient in smaller sampling areas (Shireman et al. 1981; Bayley and Austen 1990).

Our data were stratified into 2 stream-size groups and 2 transmittance groups, and we built predictive models based on these groupings. However, we believe that recapture efficiency probably varies as a continuous function of stream size and transmittance. Estimates of efficiency will probably be less accurate for sampling sites close to the dividing lines that we placed between strata--100 ft^3/s and 20% transmittance. As additional data are collected on efficiency, perhaps multivariate models can be developed that treat these variables as continuous.

Our study joins previous ones in assuming that the behavior and recapture of recently stressed, fin-clipped fish are identical to those of undisturbed fish. Unusual behavior by our "test" fish could possibly have biased our recapture estimates, resulting in either over- or under-estimates of efficiency. An experimental test of this assumption would be valuable.

Samples of fishes collected with rotenone provide fair estimates of total standing crop of a stream reach but greatly underestimate numerical abundance. We developed predictive models to be applied to discreet discharge and transmittance "stream types". However, our data displayed high variability common to such efforts (due in part to small sample sizes for certain groups; Bayley and Austen 1990; Bayley and Dowling 1990). We recommend that additional data on recapture efficiencies be collected to improve precision and accuracy of efficiency models.

Acknowledgments

We thank the many biologists and technicians who helped with the collection, marking, and recovery of fish. Those supervising field operations included D. Anson, J. Dexter, J. Drew, J. Duffy, L. Hay, J. Leonardi, H. Miller, D. Nelson, V. Nurenberg, T. Rozich, and G. Towns. B. Brown, J. Hudson, J. Okey, D. Shepherd, and R. Stearley provided extensive assistance with field operations. A. Sutton drafted the figures. J. Schneider reviewed this manuscript.

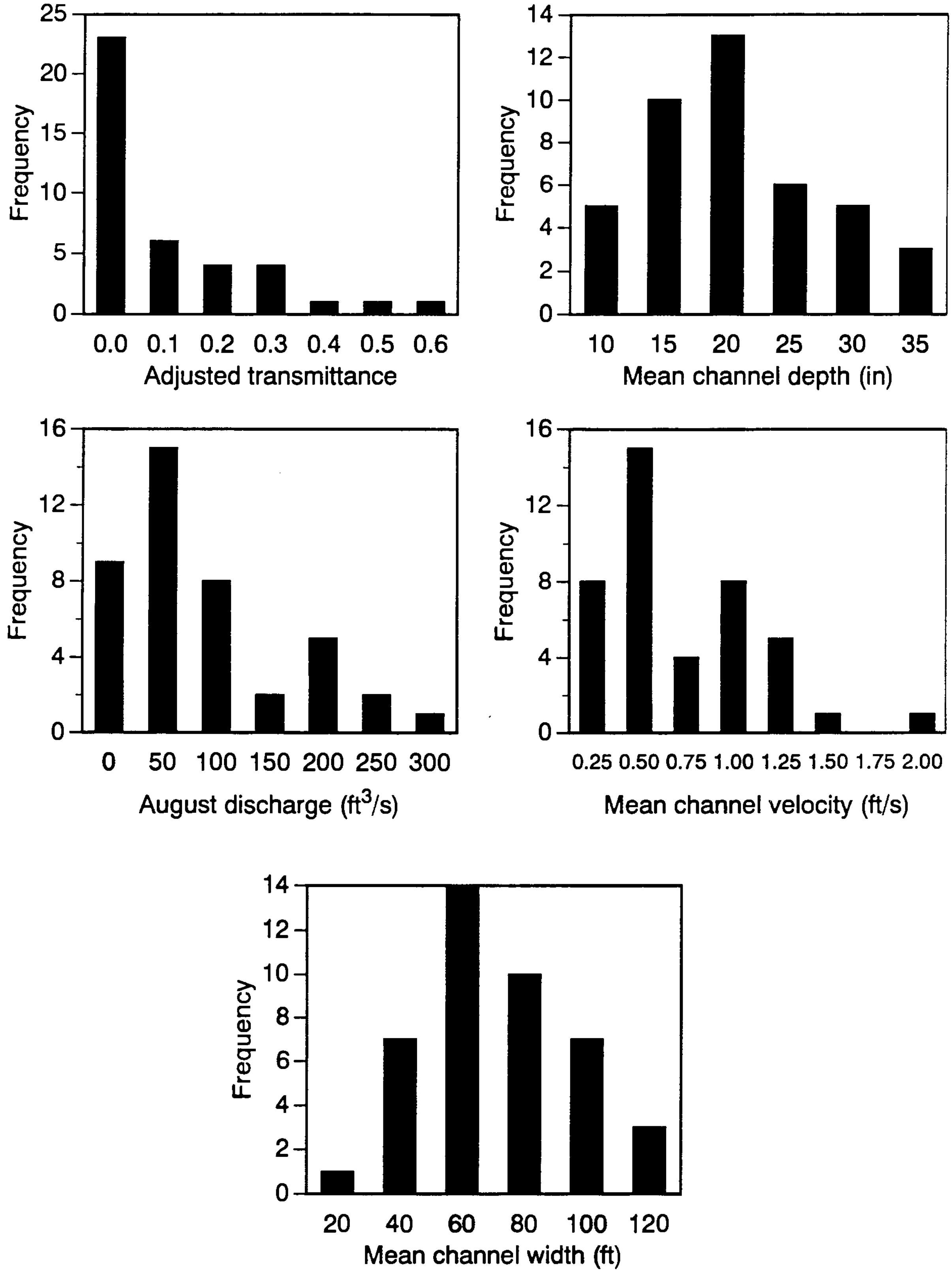

Figure 1.—Frequency distributions of physical characteristics at riverine sites where rotenone efficiency was tested.

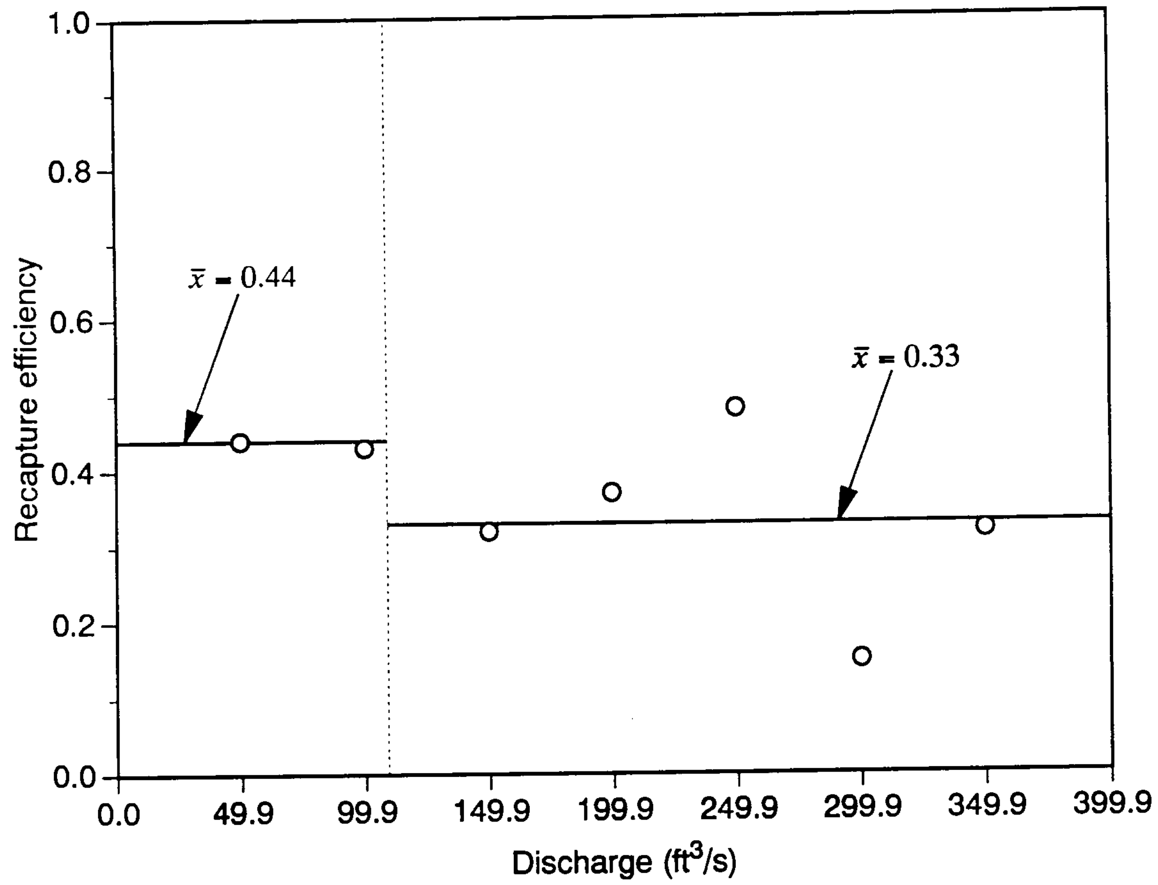

Figure 2.—The relationship between rotenone recapture efficiency and discharge for midwater fishes. The separation point between low- and high-discharge groups is shown by a vertical dotted line.

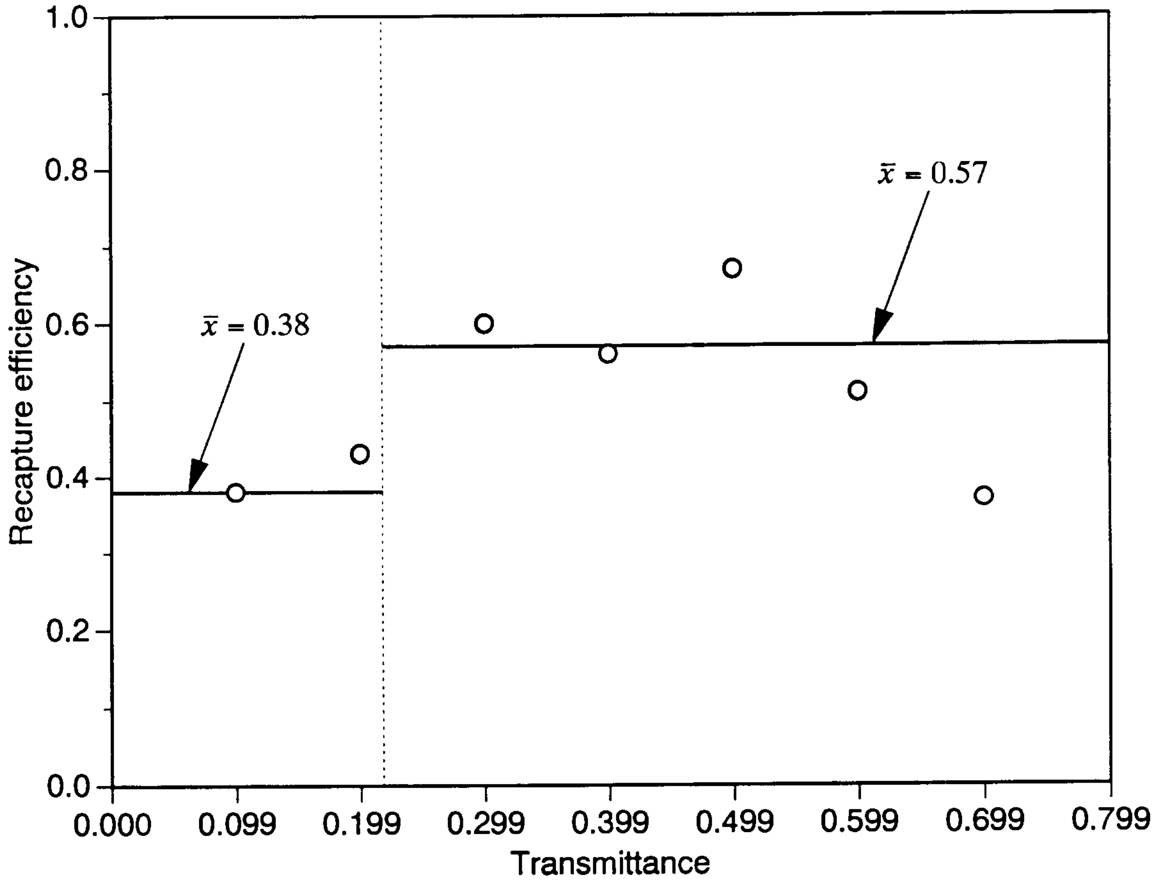

Figure 3.—The relationship between rotenone recapture efficiency and transmittance for midwater fishes. The separation point between low- and high-transmittance groups is shown by a vertical dotted line.

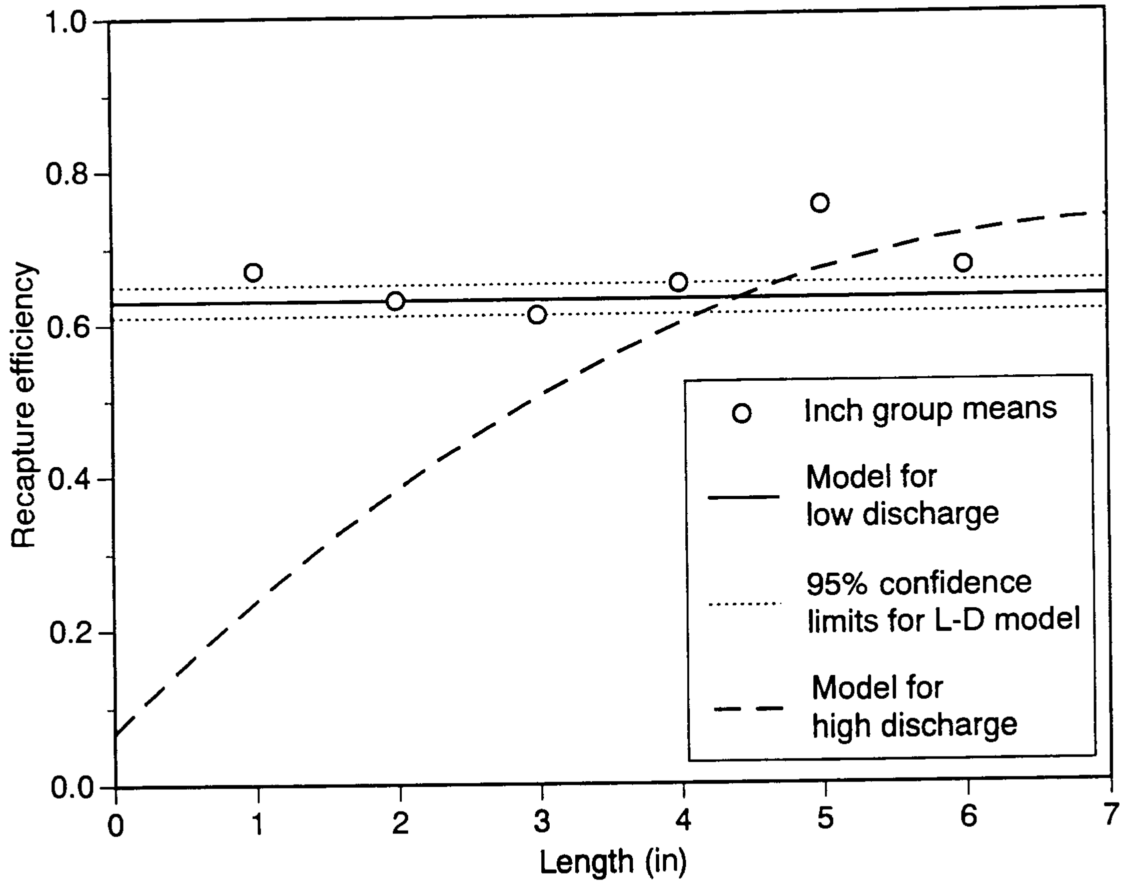

Figure 4.—Model of recapture efficiency vs. fish length for topwater fishes under low discharge conditions. Efficiency statistics are:

Mean = 0.63
Confidence Interval = 0.02

Equations for estimating total rotenone collected fishes:

$$estimate = \frac{sample}{0.63}$$

$$2SE = 2\sqrt{estimate^2 * 0.000252}$$

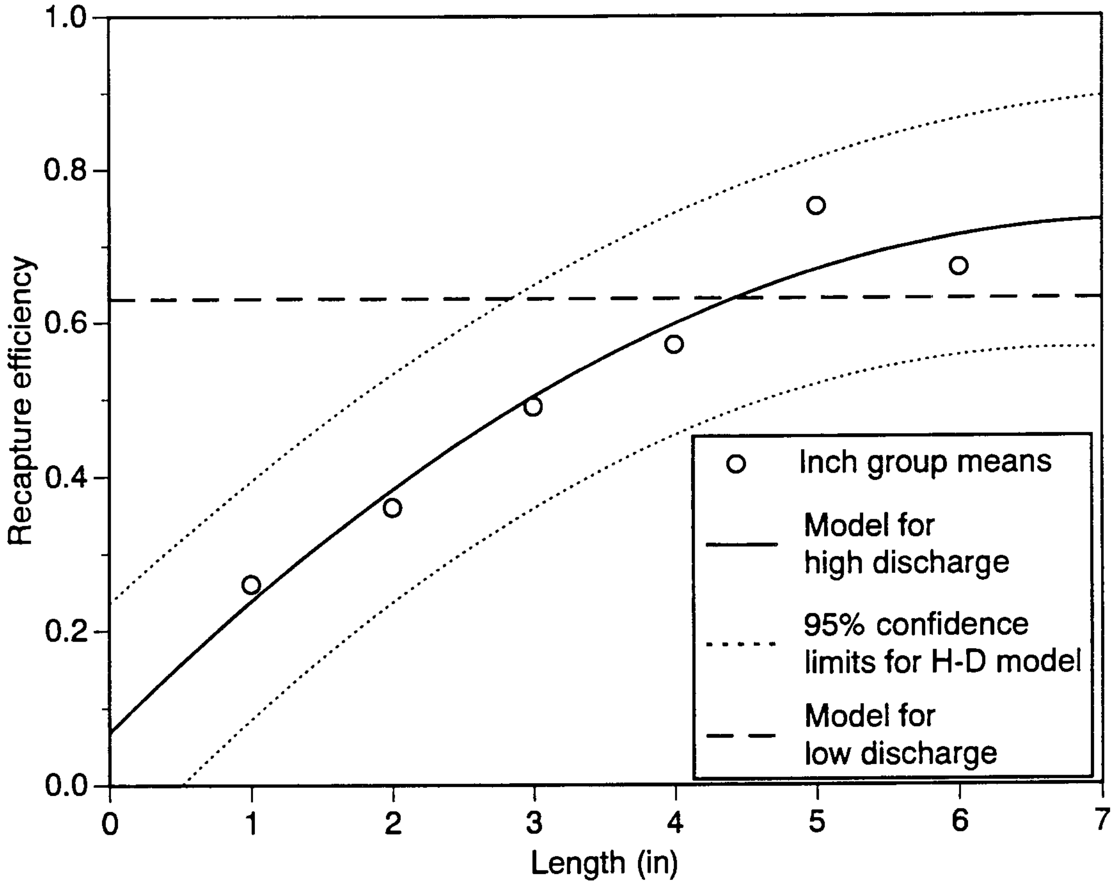

Figure 5.—Model of recapture efficiency vs. fish length for topwater fishes under high discharge conditions. Regression coefficients are:

$$Y = 0.0700 + 0.1818X - 0.0125X^2$$

$$CI = 2.13 * 0.0658\sqrt{1 + 0.0556 + \frac{(3.50 - X)^2}{53} + \frac{(15.17 - X^2)^2}{2686}}$$

Equations for estimating total rotenone collected fishes:

$$estimate = \frac{sample}{Y}$$

$$2SE = 2\sqrt{estimate^2 * \left(\frac{S_Y{}^2}{Y^2}\right)}$$

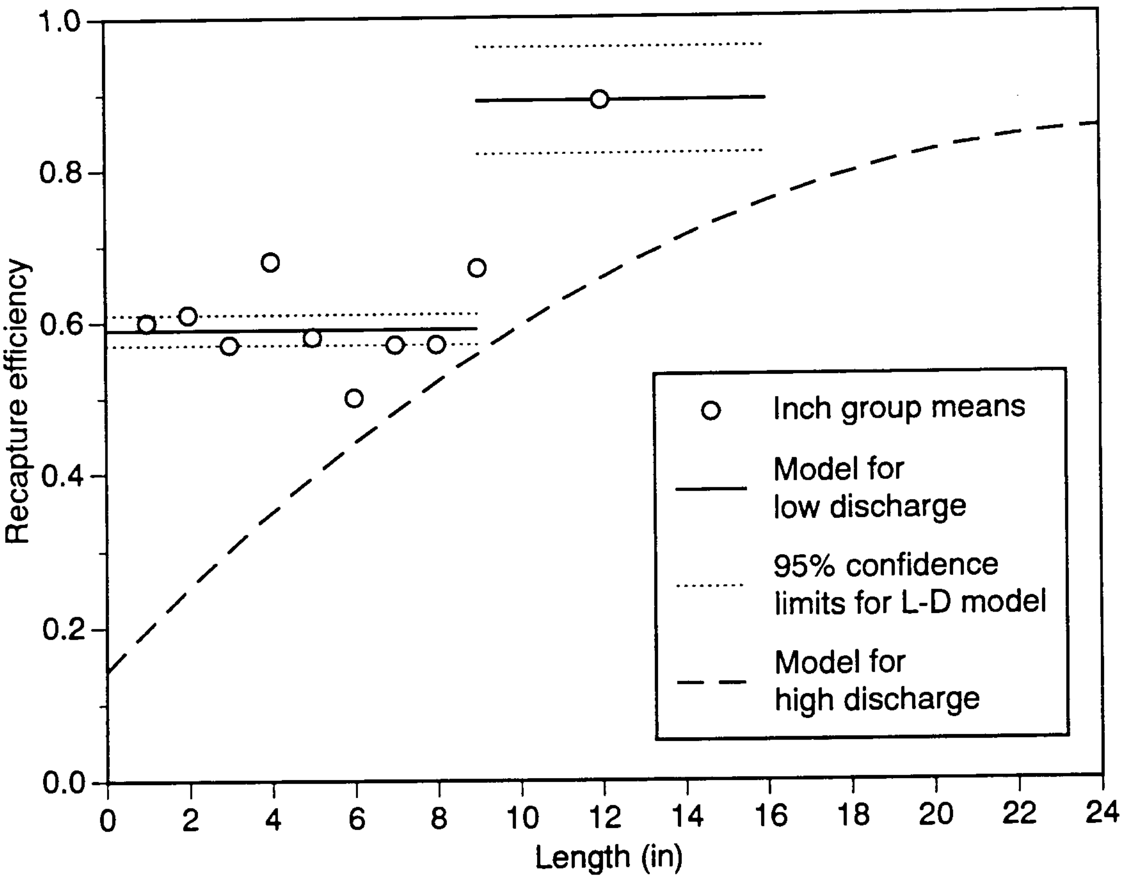

Figure 6.—Model of recapture efficiency vs. fish length for midwater fishes under low discharge and high transmittance conditions. Efficiency statistics for fishes 1-9 in.:

Mean = 0.59
Confidence Interval = 0.02

Equations for estimating total rotenone collected fishes 1-9 in.:

$$estimate = \frac{sample}{0.59}$$

$$2SE = 2\sqrt{estimate^2 * 0.000287}$$

Efficiency statistics for fishes ≥10 in.:

Mean = 0.89
Confidence Interval = 0.07

Equations for estimating total rotenone collected fishes ≥10 in.:

$$estimate = \frac{sample}{0.89}$$

$$2SE = 2\sqrt{estimate^2 * 0.001136}$$

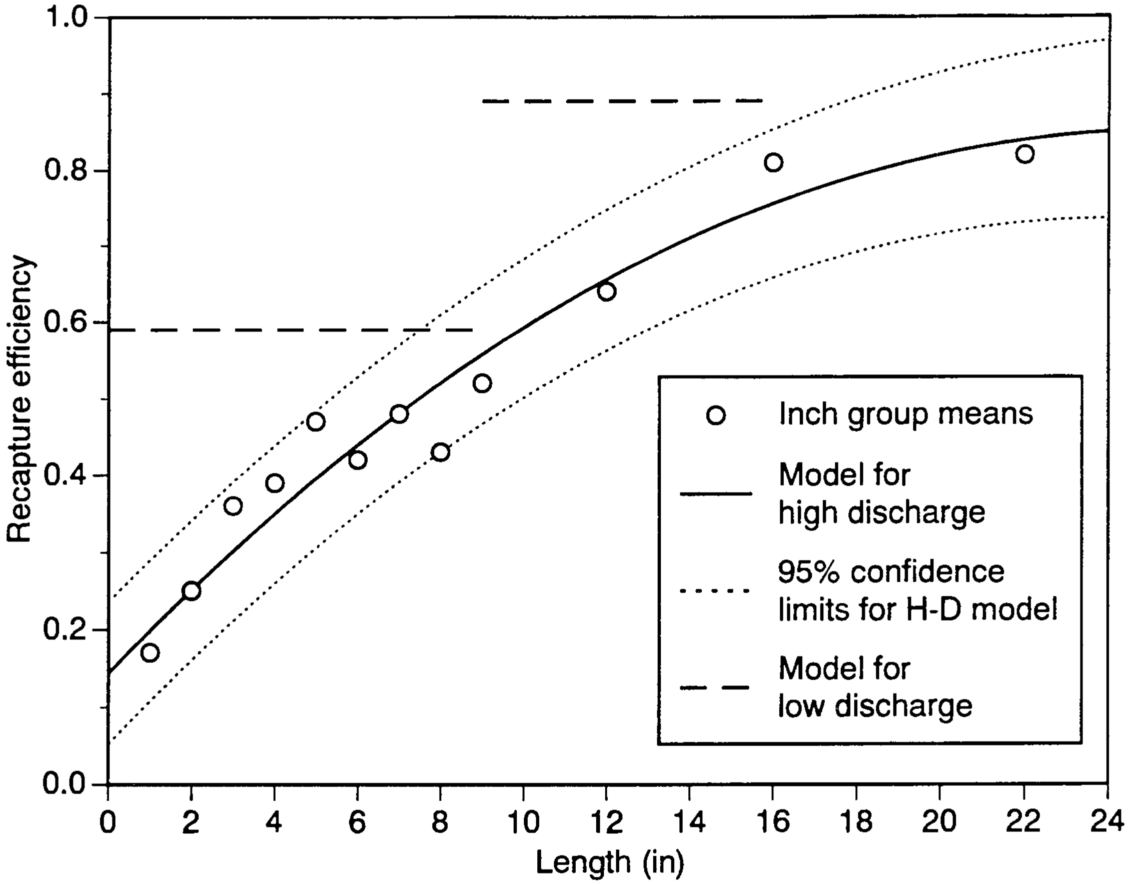

Figure 7.—Model of recapture efficiency vs. fish length for midwater fishes under high discharge and high transmittance, low discharge and low transmittance, or high discharge and low transmittance conditions. Regression coefficients are:

$$Y = 0.1378 + 0.0561X - 0.0011X^2$$

$$CI = 2.04 * 0.0446\sqrt{1 + 0.0278 + \frac{(7.92 - X)^2}{1251} + \frac{\left(97.42 - X^2\right)^2}{665941}}$$

Equations for estimating total rotenone collected fishes:

$$estimate = \frac{sample}{Y}$$

$$2SE = 2\sqrt{estimate^2 * \left(\frac{{S_Y}^2}{Y^2}\right)}$$

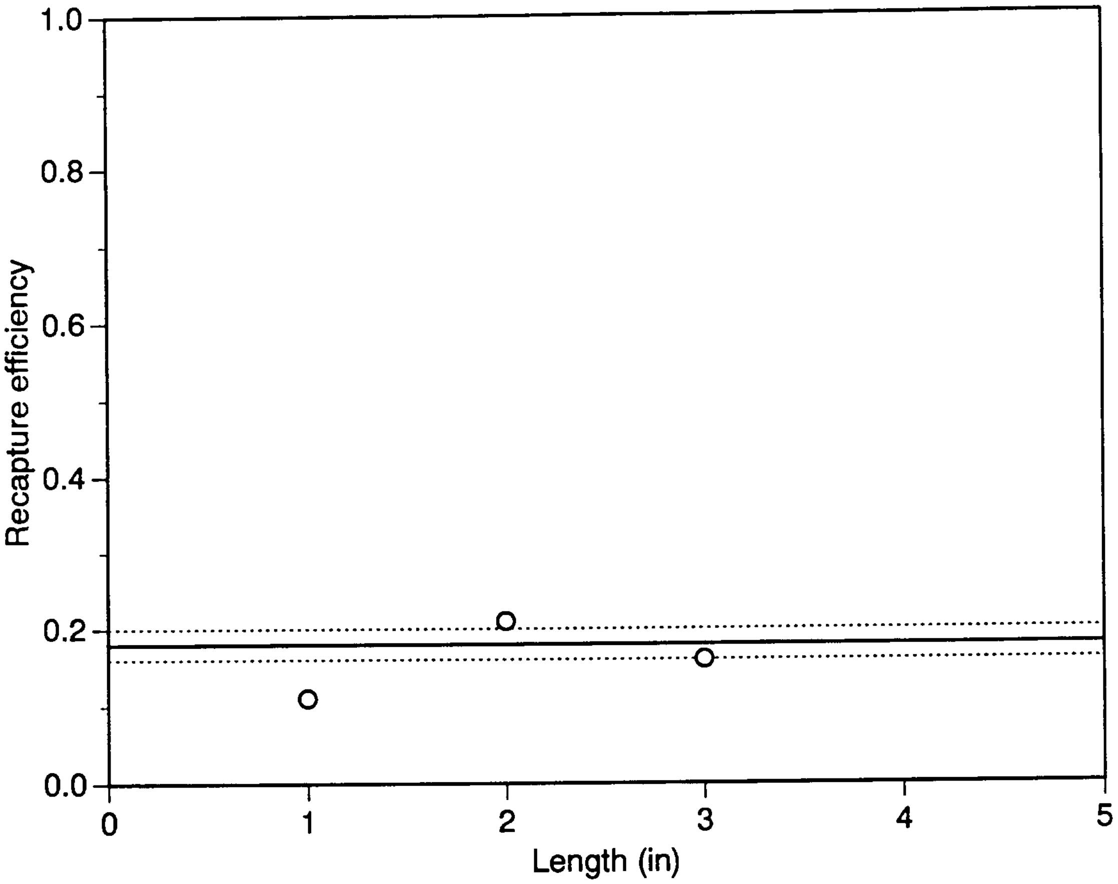

Figure 8.—Model of recapture efficiency vs. fish length for benthic fishes. Efficiency statistics are:

Mean = 0.18
Confidence Interval = 0.02

Equations for estimating total rotenone collected fishes:

$$estimate = \frac{sample}{0.18}$$

$$2SE = 2\sqrt{estimate^2 * 0.003086}$$

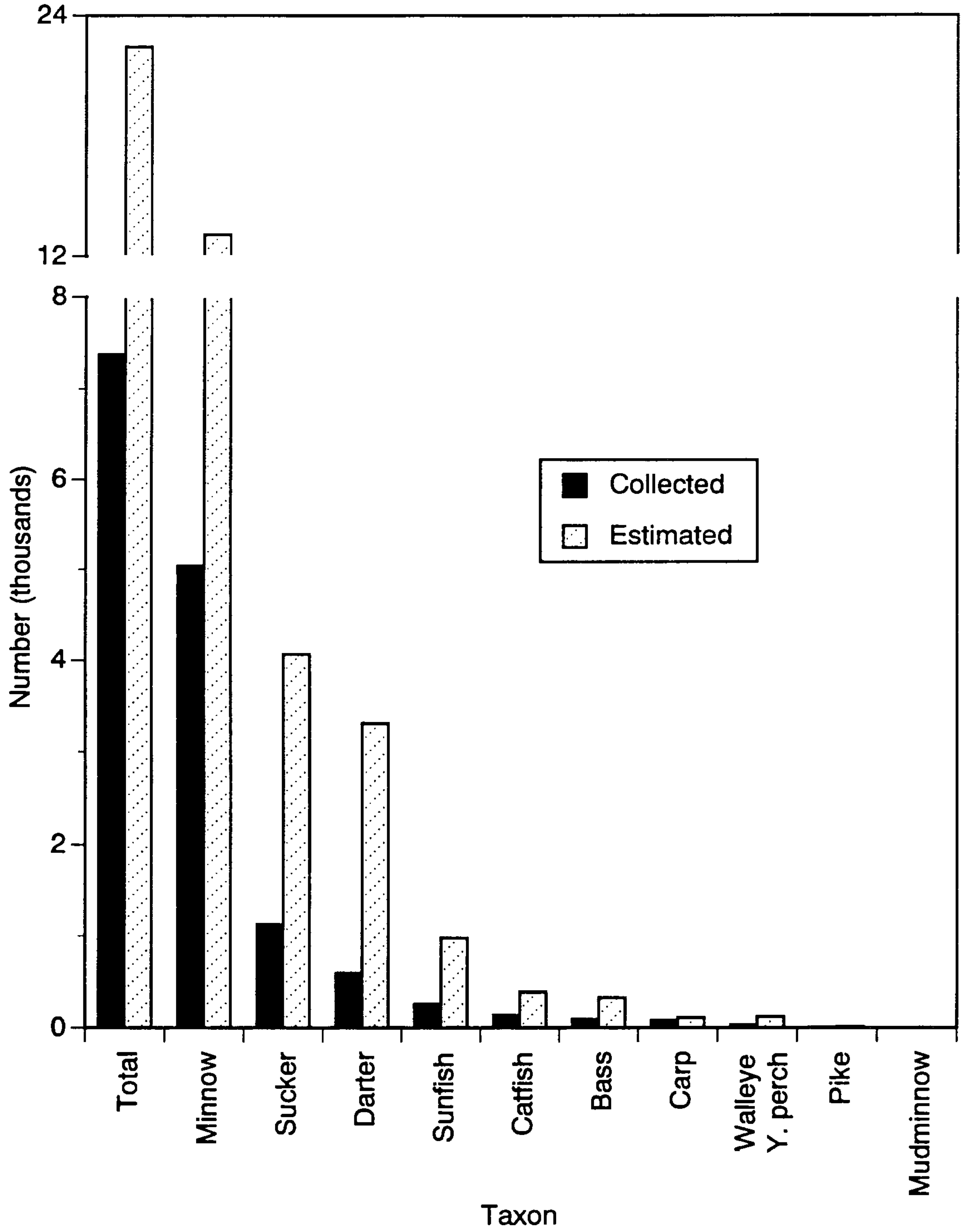

Figure 9.—Comparison, by taxon, of numbers of fish collected using rotenone vs. estimated total abundance for the St. Joseph River at Athens Road.

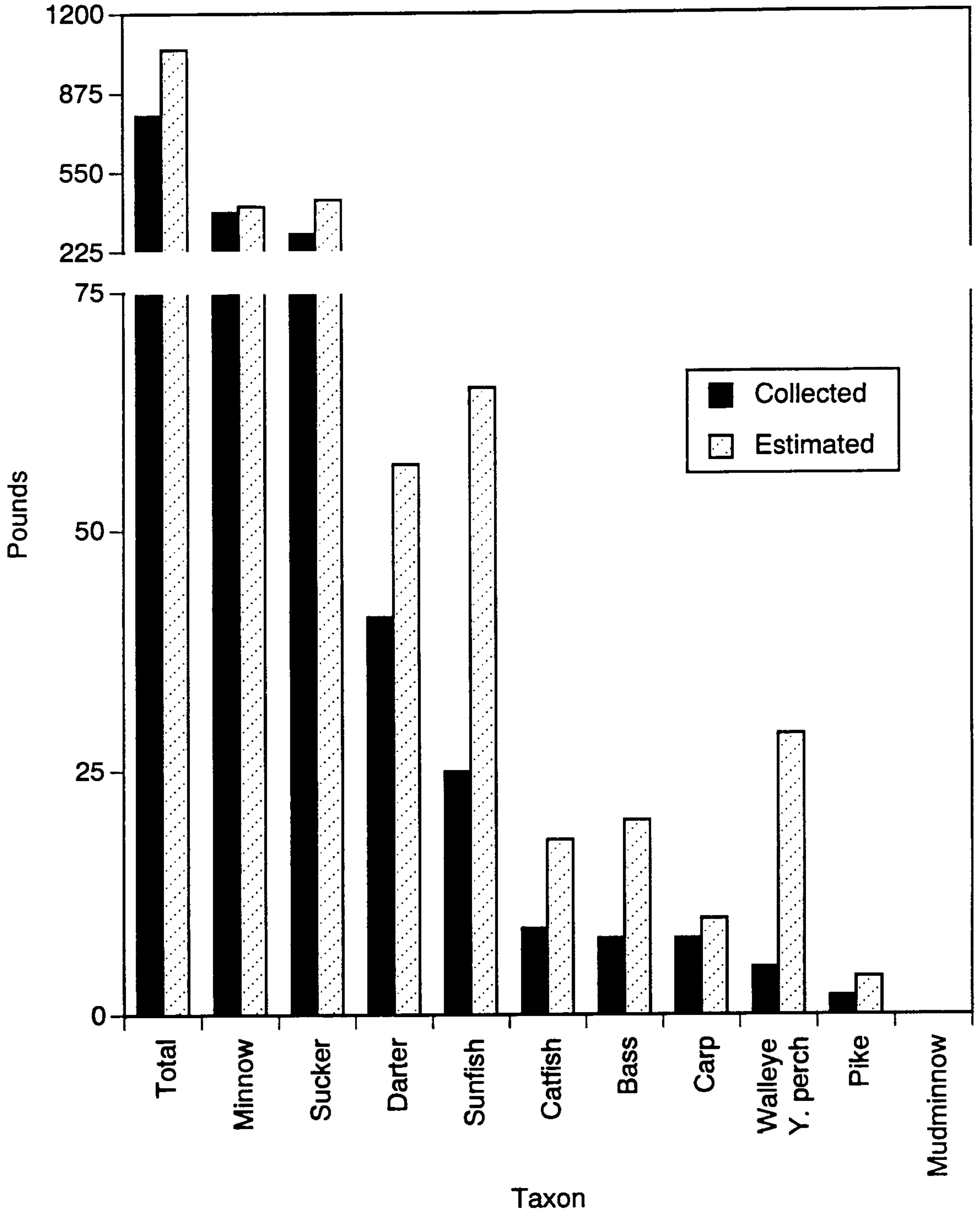

Figure 10.—Comparison, by taxon, of pounds of fish collected using rotenone vs. estimated total pounds for the St. Joseph River at Athens Road.

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Appendix 1. —Physical characteristics of sites sampled with rotenone, grouped by transmittance and discharge.

Watershed	River stream	Location	Transmittance	Discharge (ft^3/s)	Depth (in)	Velocity (ft/s)	Width (ft)
Low transmittance and low discharge							
Cass	Cass River	Deckerville Rd.	<0.001	36	24	0.67	60
Cass	Cass River	Cemetery Rd.	<0.001	28	16	0.49	55
Cass	Cass River	Decker Rd.	0.016	13	10	0.30	50
Dowagiac	Dowagic River	Frost Rd.	0.014	94	23	0.64	41
Dowagiac	Dowagiac River	Creek Rd.	0.182	50	16	0.52	38
Looking Glass	Looking Glass River	Lowell Rd.	<0.001	60	24	0.70	58
Looking Glass	Looking Glass River	Bauer Rd.	0.008	63	18	0.53	65
Looking Glass	Looking Glass River	Upton Rd.	0.023	54	36	1.39	60
Looking Glass	Looking Glass River	BeaRd.slee Rd.	0.036	21	18	0.52	31
Looking Glass	Looking Glass River	Williams Rd.	0.156	75	24	0.85	70
Maple	Maple River	Faragher Rd.	0.006	80	28	1.20	43
Maple	Maple River	State Rd.	0.043	55	24	0.69	41
Maple	Maple River	Ransom Rd.	0.161	60	14	0.44	43
Shiawassee	Shiawassee River	W. Gary Rd.	<0.001	80	24	0.97	60
Shiawassee	Shiawassee River	Juddville Rd.	<0.001	57	18	0.53	94
Shiawassee	Shiawassee River	Bancroft Rd.	0.013	75	18	0.53	86
St. Joseph	St. Joseph River	22 Mile Rd.	0.001	31	15	0.46	48
High transmittance and low discharge							
Dowagiac	Dowagiac River	Atwood Rd.	0.313	23	15	0.45	34
Galien	S. Br. Galien River	Lakeside Rd.	0.488	31	14	0.36	30
Looking Glass	Looking Glass River	Morrice Rd.	0.395	10	12	0.31	19
Looking Glass	Looking Glass River	Monroe Rd.	0.542	74	24	0.77	70
Maple	Maple River	Warren Rd.	0.395	35	12	0.32	26
Maple	Fish Creek	Fensk Rd.	0.631	78	18	0.54	75
Paw Paw	N. Br. Galien River.	3550th St.	0.340	52	22	0.63	41

Appendix 1.—Continued.

Watershed	River stream	Location	Transmittance	Discharge (ft^3/s)	Depth (in)	Velocity (ft/s)	Width (ft)
Low transmittance and high discharge							
Cass	Cass River	Perry Creek	<0.001	146	24	1.00	115
Dowagiac	Dowagiac River	Niles Dam	0.211	261	19	0.57	78
Maple	Maple River	M-21	<0.001	250	30	1.38	100
Maple	Maple River	Maple Rapids	0.020	100	30	1.24	87
Muskegon	Muskegon River	Jonesville		120	31	1.38	81
Paw Paw	Paw Paw River	Lawrence	0.098	180	30	1.28	68
Paw Paw	Paw Paw River	County Line Rd.	0.098	204	30	1.35	79
Paw Paw	Paw Paw River	59.5 St.	0.133	183	26	1.06	80
Paw Paw	Paw Paw River	Watervliet Dam	0.168	226	24	1.01	74
St. Joseph	St. Joseph River	Athens Rd.	<0.001	125	23	0.65	103
Thunder Bay	Thunder Bay River	James Farm	<0.001	240	38	2.02	55
Thunder Bay	Thunder Bay River	Long Rapids Rd.	<0.001	300	37	1.52	100
Thunder Bay	Thunder Bay River	Hillman	0.014	228	23	0.66	80
Thunder Bay	Lower S. Br. Thunder Bay River	Indian River Rd.	0.171	146	23	0.65	100
High transmittance and high discharge							
Paw Paw	S. Br. Paw Paw River	3750th St.		113	28	1.17	30
Thunder Bay	Thunder Bay River	M-32	0.242	228	28	1.21	94
Thunder Bay	Thunder Bay River	M-33	0.258	118	26	1.02	39
Thunder Bay	Wolf Creek	Beaver Lake Rd.	0.258	120	26	1.03	45